Total Coliform Rule / Distribution System Stakeholder Technical Workshop

Potential Use of Data to Characterize Physical Distribution System Integrity Problems

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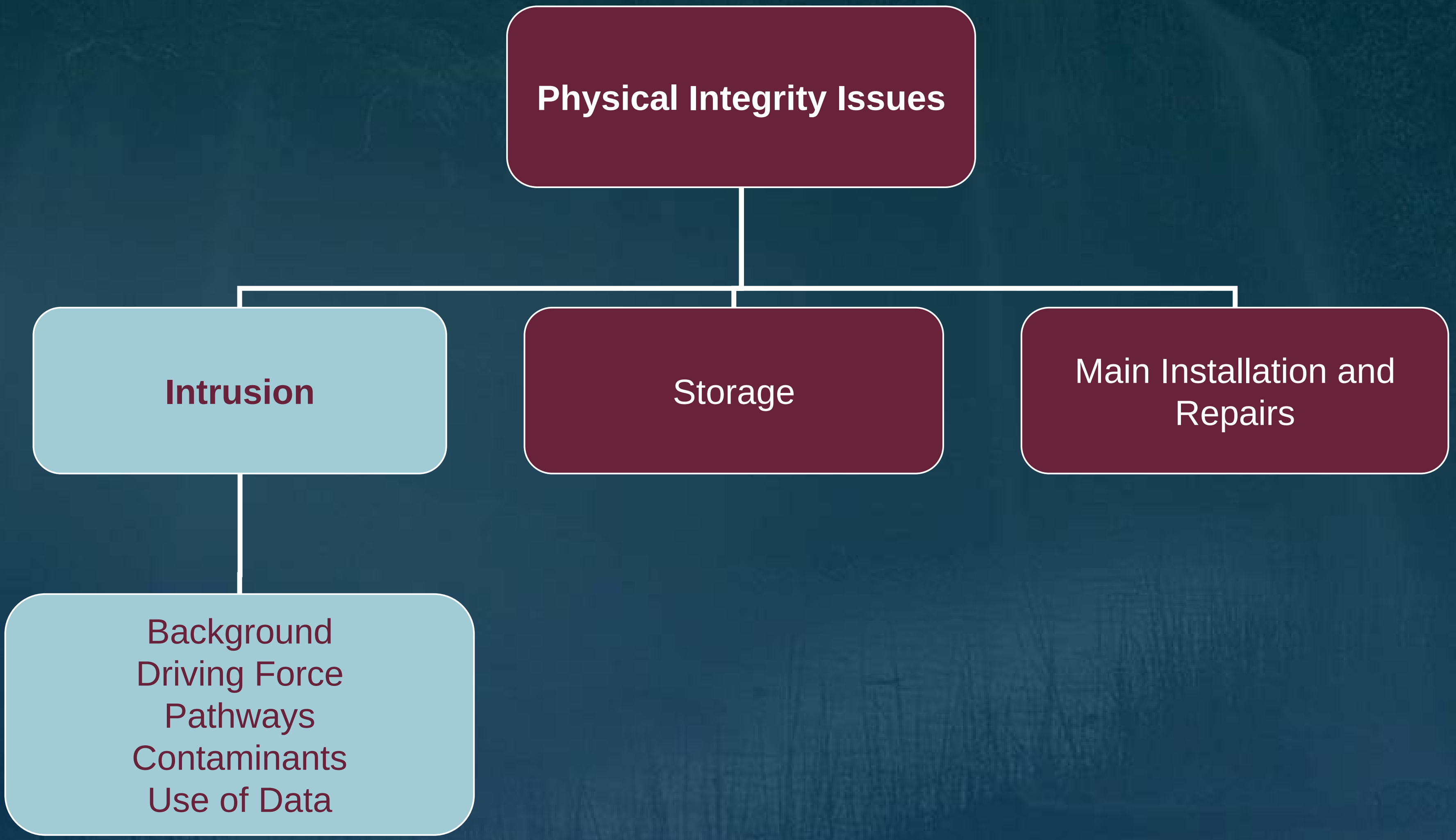
Presentation Objective:

- Describe data available for characterizing distribution system physical integrity issues
  - *Intrusion*
  - *Storage Facilities*
  - *Main Installation and Repair*
- Describe potential uses of the data

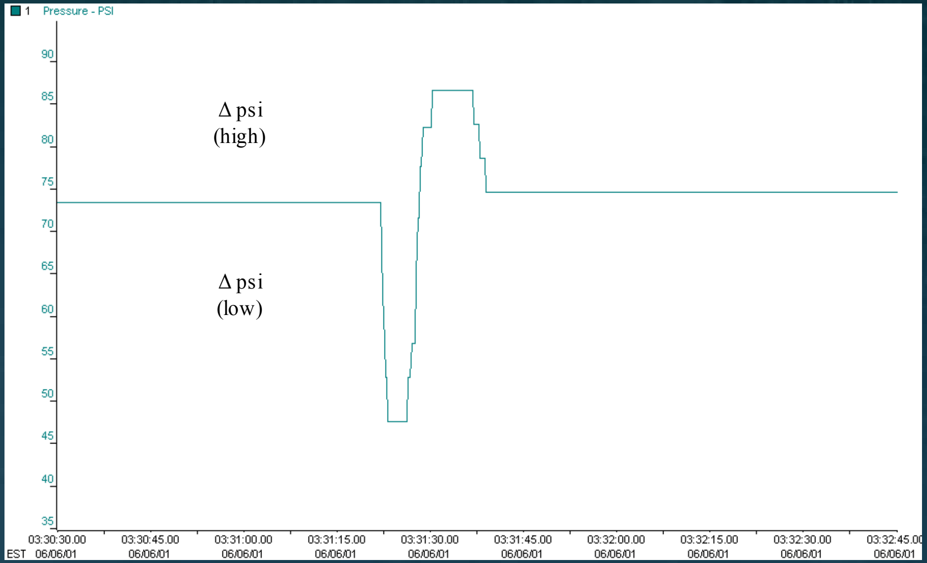

Physical Integrity Issues
Intrusion
Storage
Main Installation and Repairs
Background
Driving Force
Pathways
Contaminants
Use of Data

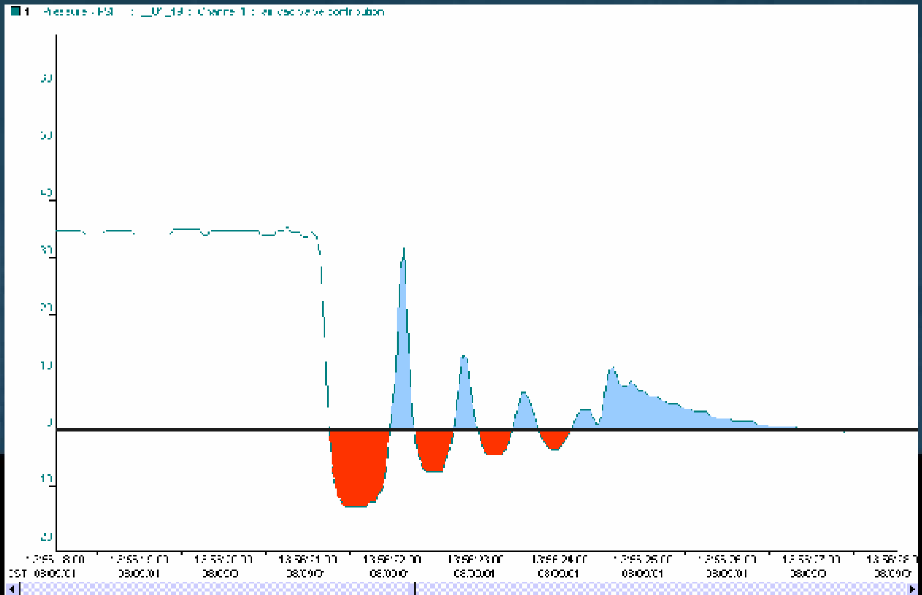
What is Intrusion?

The backflow or backsiphonage of water into a distribution main through leaks, cracks, submerged air valves, faulty seals, or other breaches, due to the development of low or negative transient pressure conditions in the main.

What is a Pressure Transient?

- Development of instantaneous low or negative pressure wave due to a sudden velocity change
- For sudden valve closure:
  - *Compression of water on upstream side*
  - *Decompression on downstream side*
- Without relief, the pressure wave travels back and forth until dissipated by friction or other dampening factors





Intrusion *Is Not* the Same As Cross Connection

- Non-potable source is not "piped" to potable source
- Contaminant sources are in the external environment
- Intrusion is more of a transient event
- Driving forces may be the same, however

Potential Causes of Pressure Transients (i.e., the Driving Force)

- Pump trip due to power failure
- Opening and closing a fire hydrant
- Altitude valve closure
- Valve operation – closing and opening
- Controlled pump start-up and shut-down
- Uncontrolled pump shut-down
- Pipeline break

Kirmeyer et al. 2001. Pathogen Intrusion into the Distribution System.

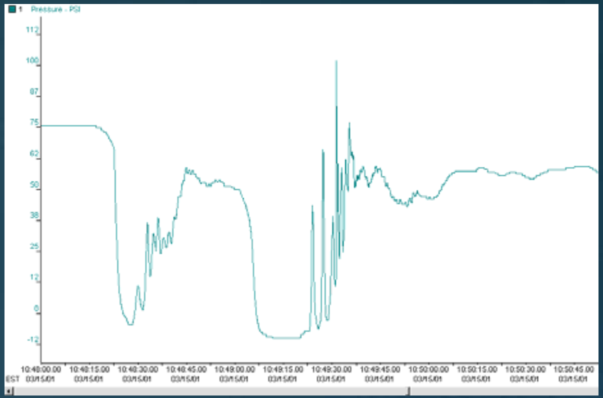
Examples of Documented Intrusion-Related Outbreaks

- Dushanbe, Tajikistan (1997)
  - *Massive epidemic of multi-drug resistant typhoid fever*
  - *8901 illnesses and 95 deaths were reported*
  - *Affected about 1% of the city's population*
  - *Low water pressure and frequent water outages had contributed to the problem (Hermin et al., 1999)*
- NY Trailer Park (2002)
  - Giardia *outbreak*
  - *6 residents became ill (Blackburn et al. 2004).*
- England, February 2001 through May 2002
  - *Sporadic Cryptosporidiosis*
  - *Strong association between self-reported diarrhea and low pressure events (Hunter et al., 2005).*

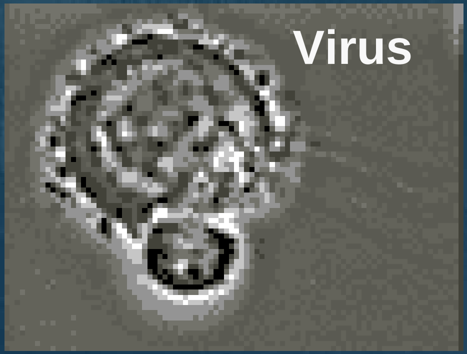
National Research Council. 2005. Public Water Supply Distribution Systems: Assessing and Reducing Risks

Three Critical Elements for Contamination to Occur Due to Intrusion

Pathway	Driving Force	Pathogens



Pressure
Reduction Event

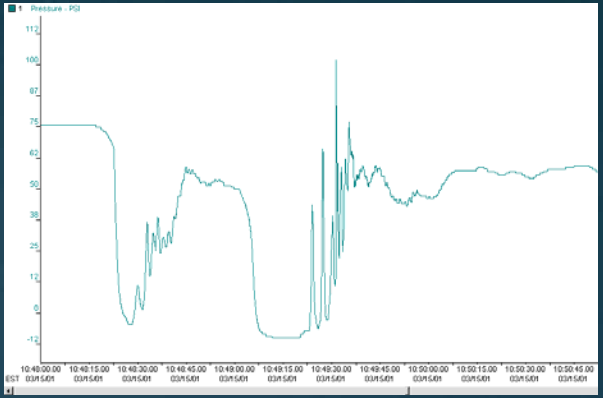


Direct Measurement of Intrusion is not Possible

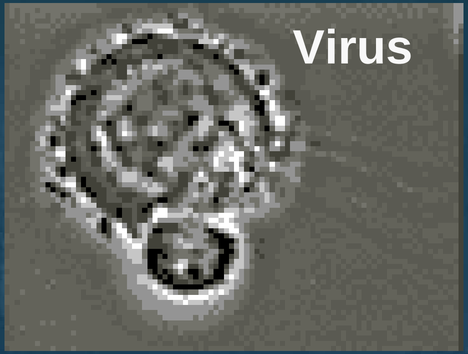
- Would need to continuously monitor downstream of every leak, submerged valve, etc.
  - *"Needle in a haystack"*

- Indirect measurement is potentially feasible
  - *Measure frequency, magnitude, duration of pressure reduction events (i.e., driving force)*
  - *Quantify number and size of pathways*
  - *Quantify presence of pathogens in vicinity of pathway*

Pathway	Driving Force	Pathogens



Pressure
Reduction Event



Pathway Data - Leakage

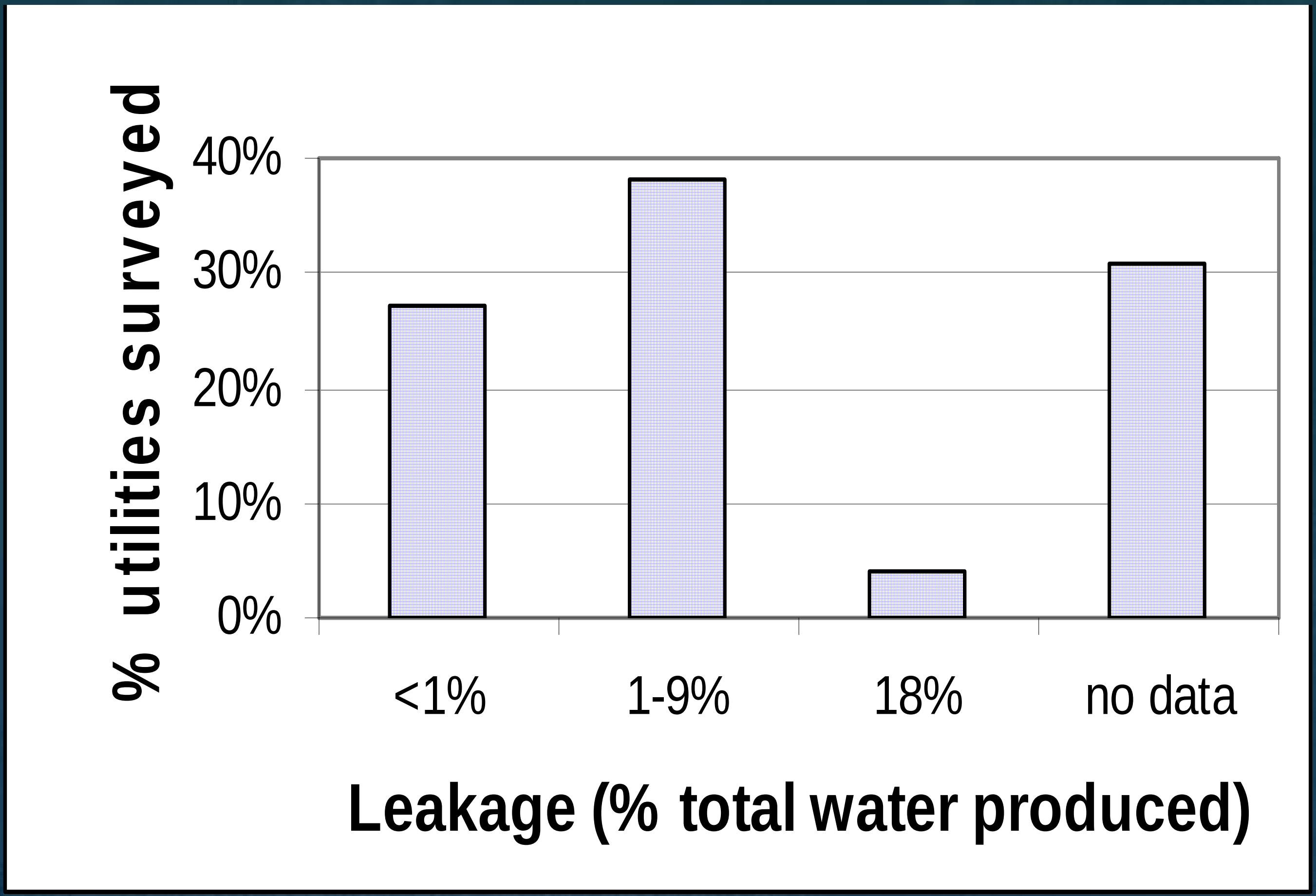
- 10% of water produced is often lost as leakage.
- Utilities reported repairing an average of 109 leaking mains annually. (This is about one leak per every six miles of main).
- Utilities reported repairing an average of 159 leaking hydrants, valves, and other appurtenances annually.
- Leak detection programs saved utilities an average of 9.8% of annual production.

Kirmeyer et al. 1994. An Assessment of Water Distribution Systems and Associated Research Needs.

1992. Water Industry Data Base

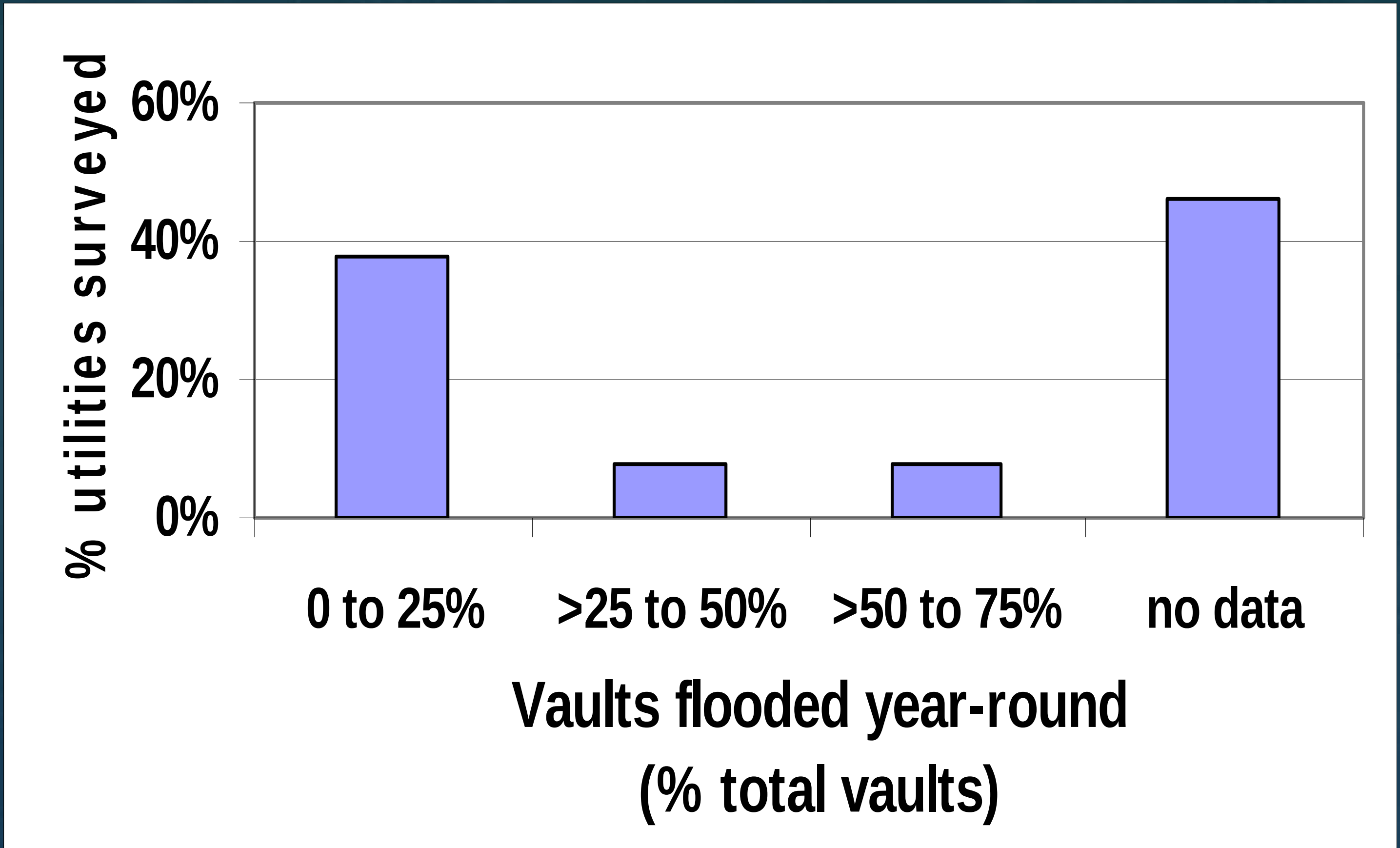
AWWA. 2003. Waterstats

Leakage Pathway



Kirmeyer et al. 2001. Pathogen Intrusion into the Distribution System.

Flooded Vault Pathway

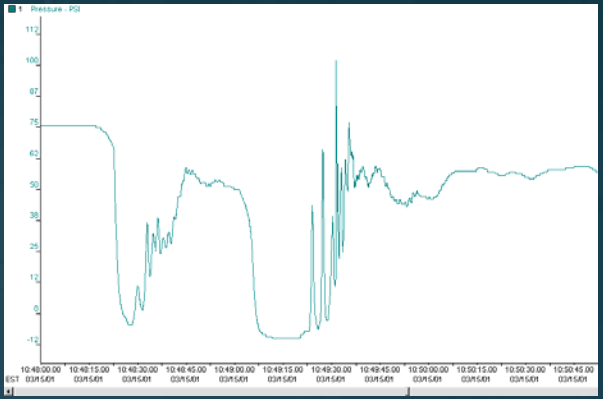


Kirmeyer et al. 2001. Pathogen Intrusion into the Distribution System.

More Detail on Flooded Vaults

- 14/26 utilities did not have information on flooding of meter and valve vaults.
- Range of flooded vaults: 0 to 80%
- 12/26 do not have standard operating procedures for valve survey/inspection – point out an industry need
- 1 utility – 100% of air/vac valve vaults had standing water.
- 1 utility - 2/147 air/vac valve vaults had standing water.

Pathway | **Driving Force** | **Pathogens**



Pressure
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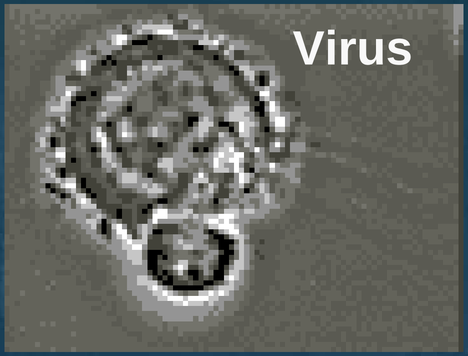


Pressure Requirements

- 30 States require systems to have an operational pressure of at least 20 psi under all flow conditions.

Summary of Minimum Pressure Requirements

Requirement	Value	Location	Source
Min. Pressure Requirement	35 psi	All points within the DS	AWWA, CA DHS
	20 psi	All ground level points	Ten State Standards

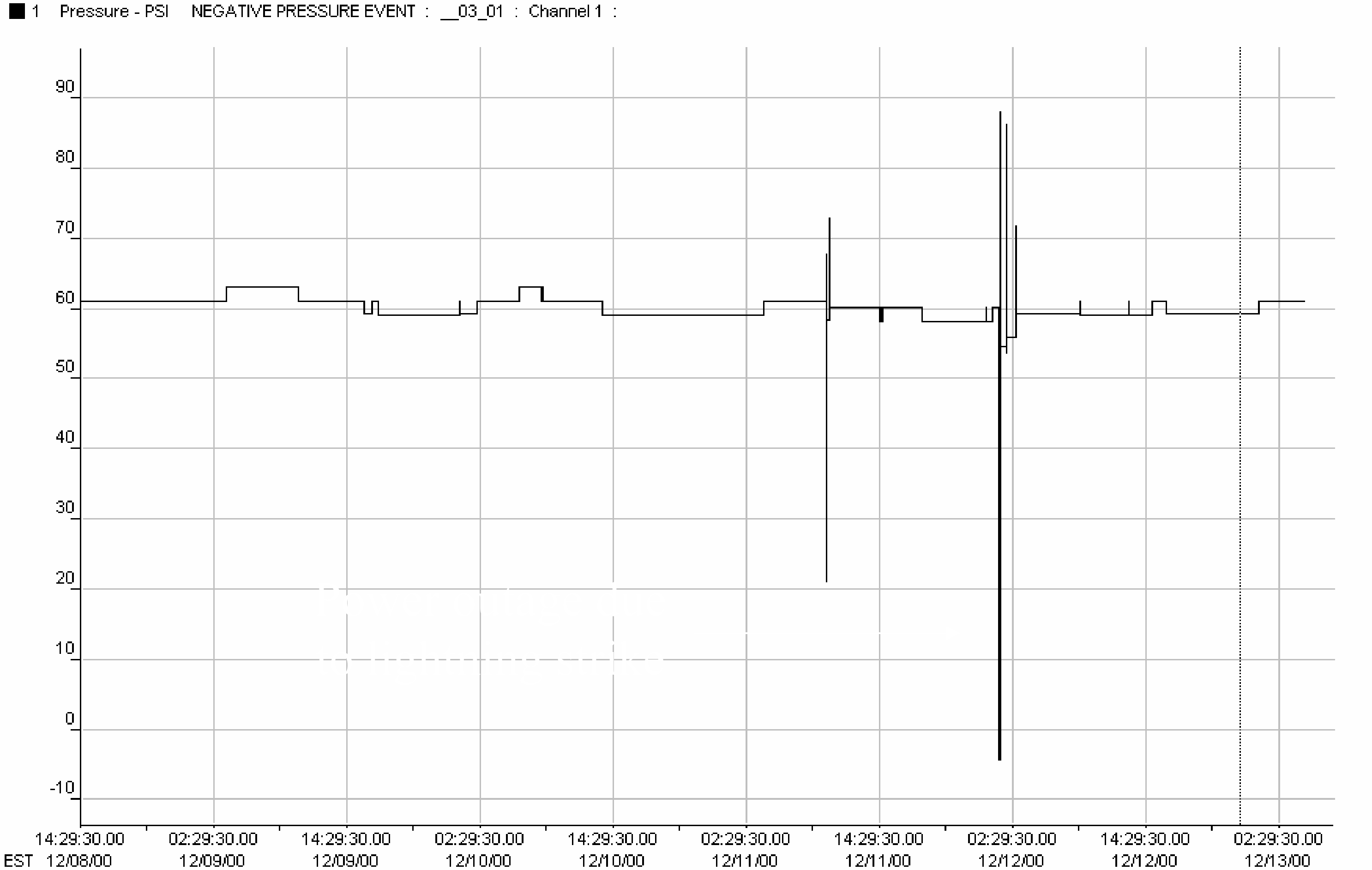
ASDWA. 2003. Unpublished Survey. 34 states responded.

Table Adapted from Kirmeyer et al. 2001. Pathogen Intrusion Into the Distribution System.

Data Sources Related to Driving Force

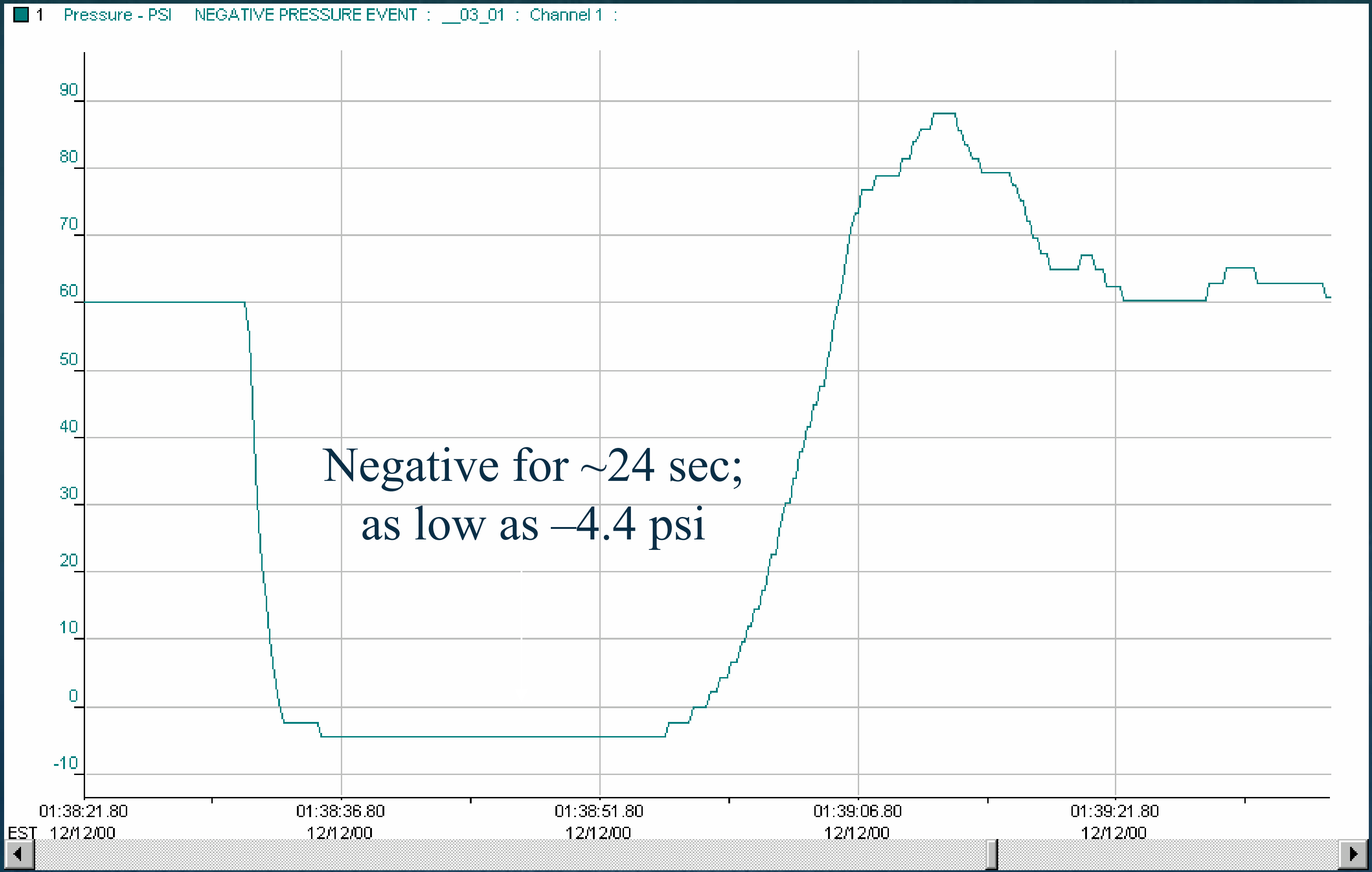
- High Speed Pressure Data Loggers
- Conventional Pressure Recording Devices
- Surge Models
- Main Break Data
- Power Loss Data

Pressure Data Logger Measures Magnitude



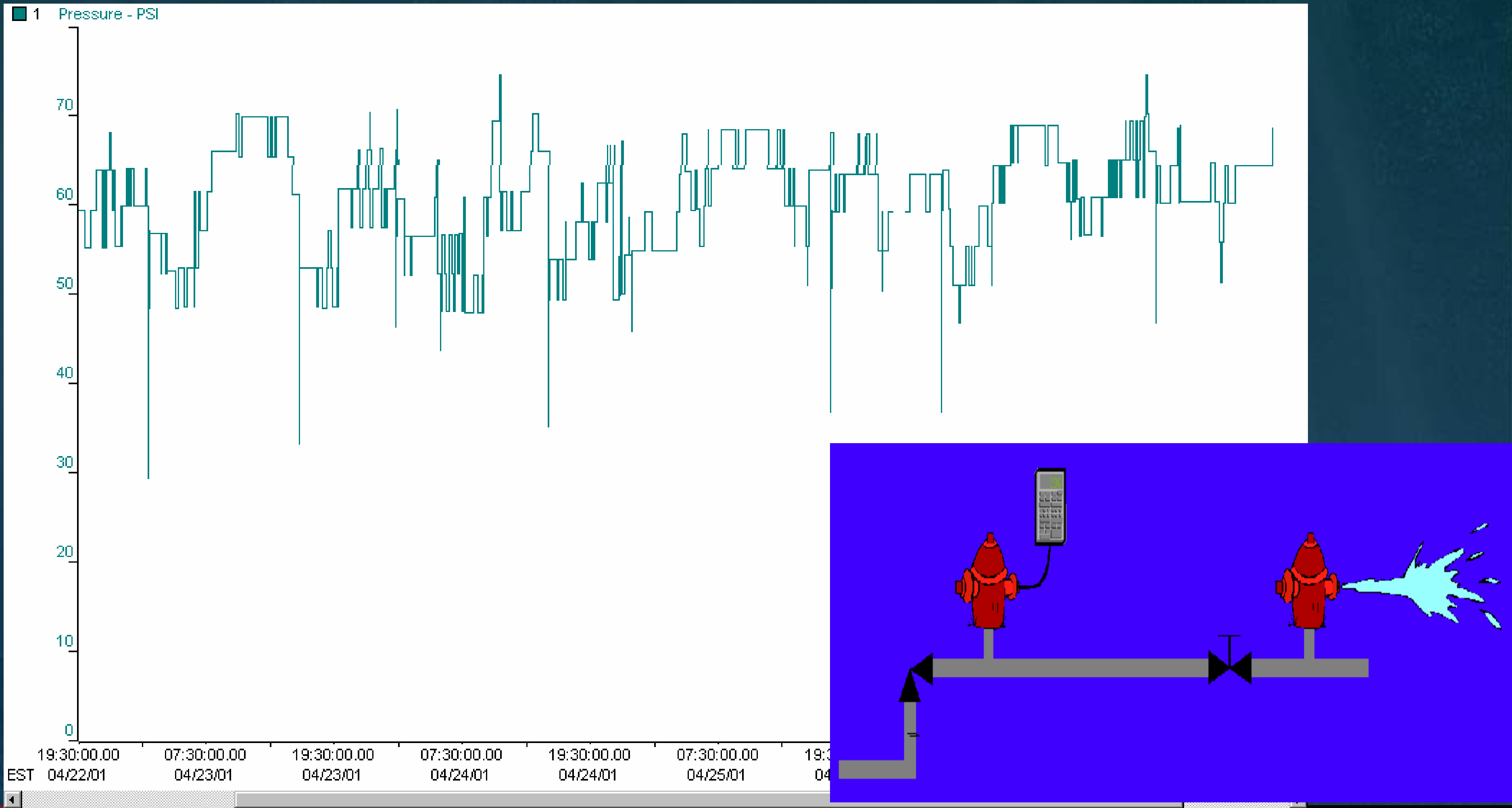
Transient follows a power outage at a pumping station

Pressure Data Logger Measures Duration



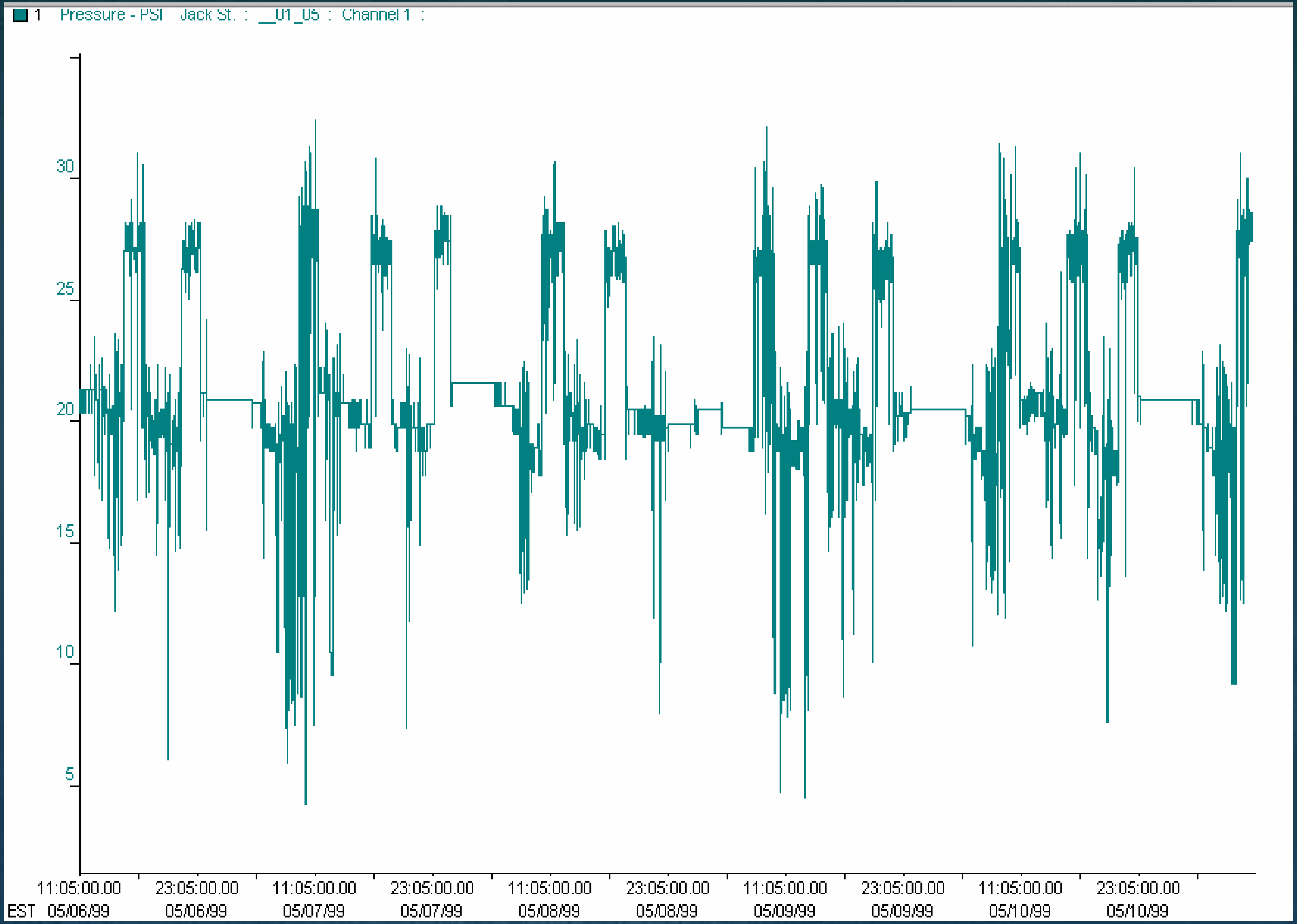
Transient follows a power outage at a pumping station

Assessment of Transient Frequency Due to Routine Flushing Activities



Friedman et al. 2004. Verification and Control of Pressure Transients and Intrusion in Distribution Systems

Frequency of Pressure Transients on Residential Line



Pressure transients measured at a hose bib outside a residence

Friedman et al. 2004. Verification and Control of Pressure Transients and Intrusion in Distribution Systems

Occurrence of Low/Negative Pressure Events

- Power Outages:
  - *50% of utilities reported 3 or less power outages each year*
  - *8% experienced more than 20 per year*
  - *15% experienced between 6 and 15 per year.*
  - *In field monitoring - 12/13 events where a negative pressure was observed were caused by sudden shut-down of pumps.*
- Note: pressure transients may be isolated to a specific pressure zone

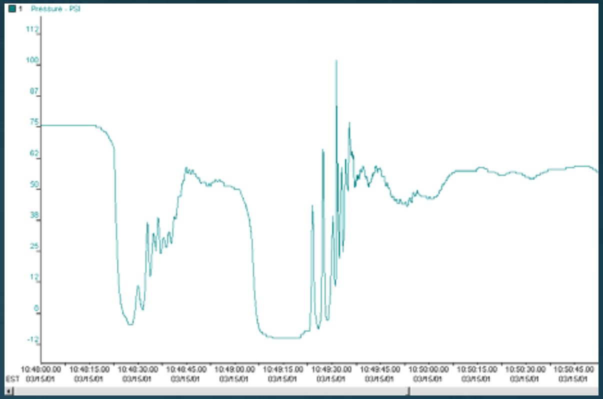
Bullets 1-3. Kirmeyer et al. 2001. Pathogen Intrusion into the Distribution System.

Bullet 4. Friedman et al. 2004. Verification and Control of Pressure Transients.

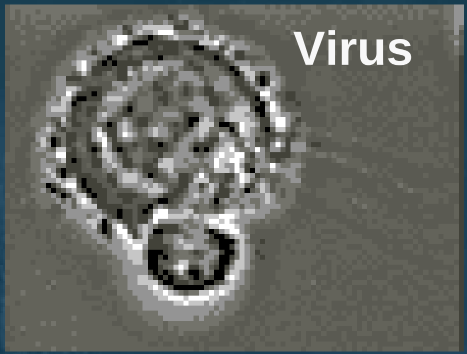
Pathway

Driving Force

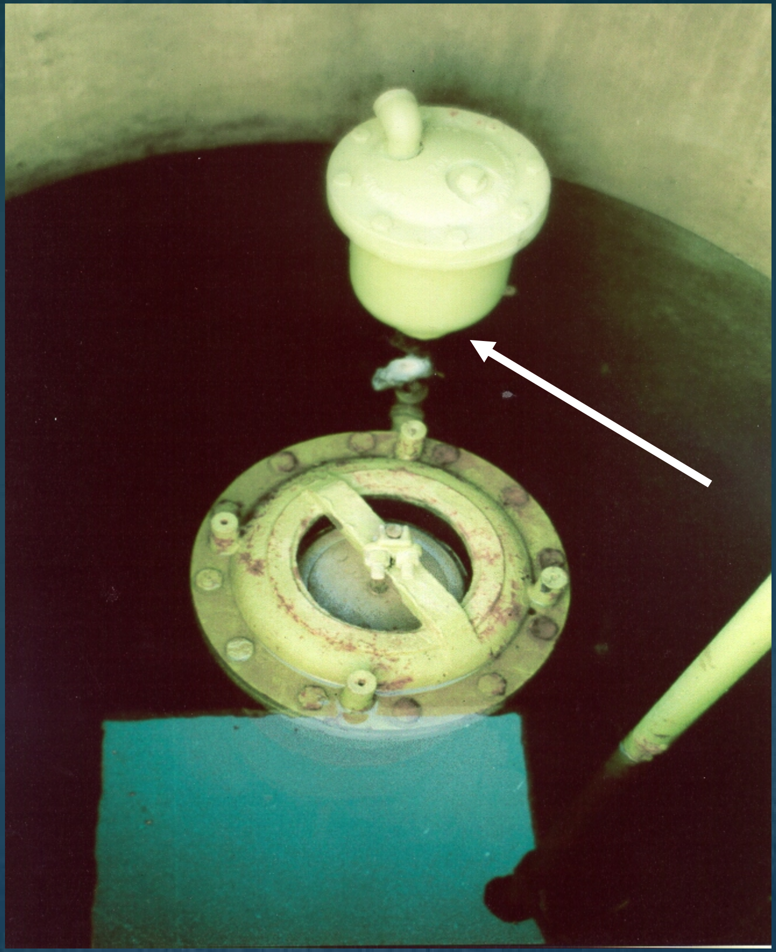
Pathogens



Pressure
Reduction Event

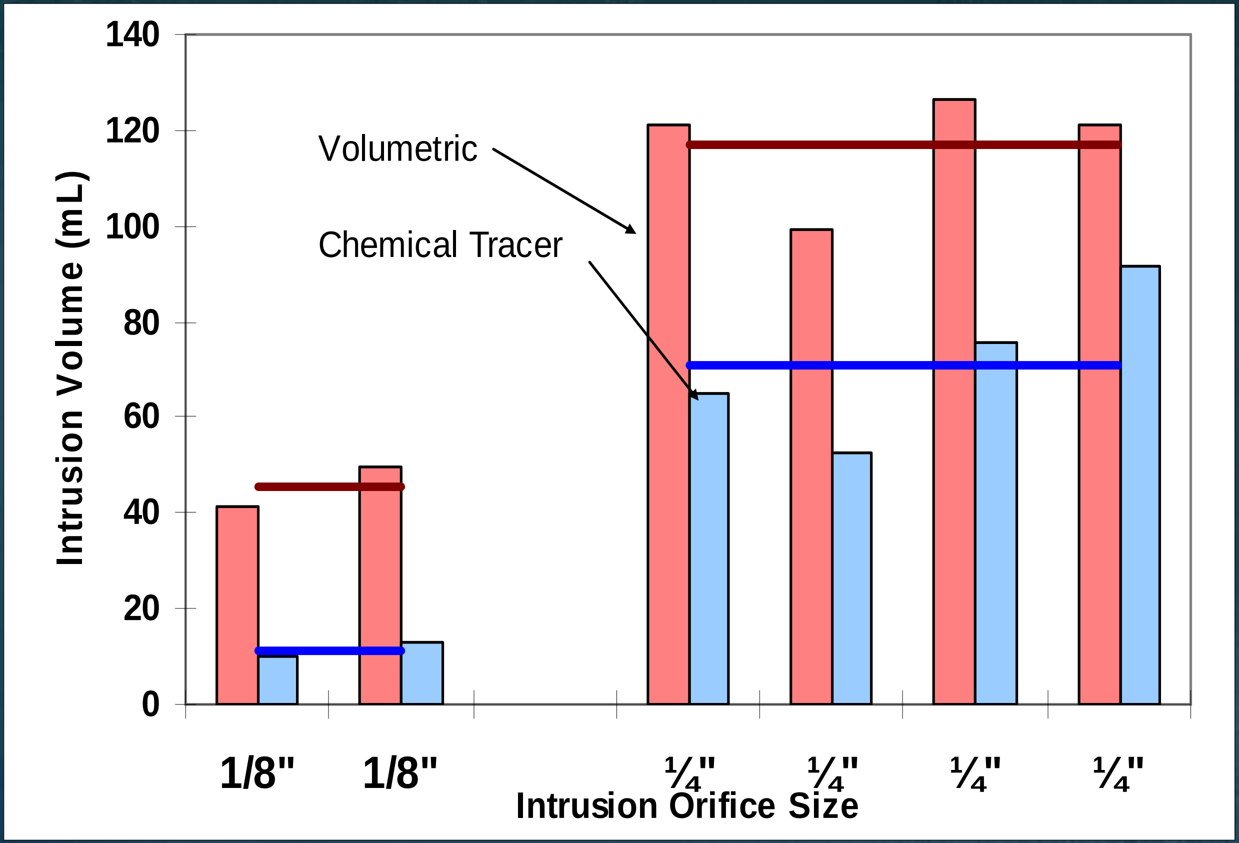


Pathogens may be present!



Estimating Intrusion Volumes

Test Rig Results



Friedman et al. 2004. Verification and Control of Pressure Transients and Intrusion in Distribution Systems

Or, conduct Modeling (to be discussed in next presentation)

Locations Susceptible to Pressure Transients

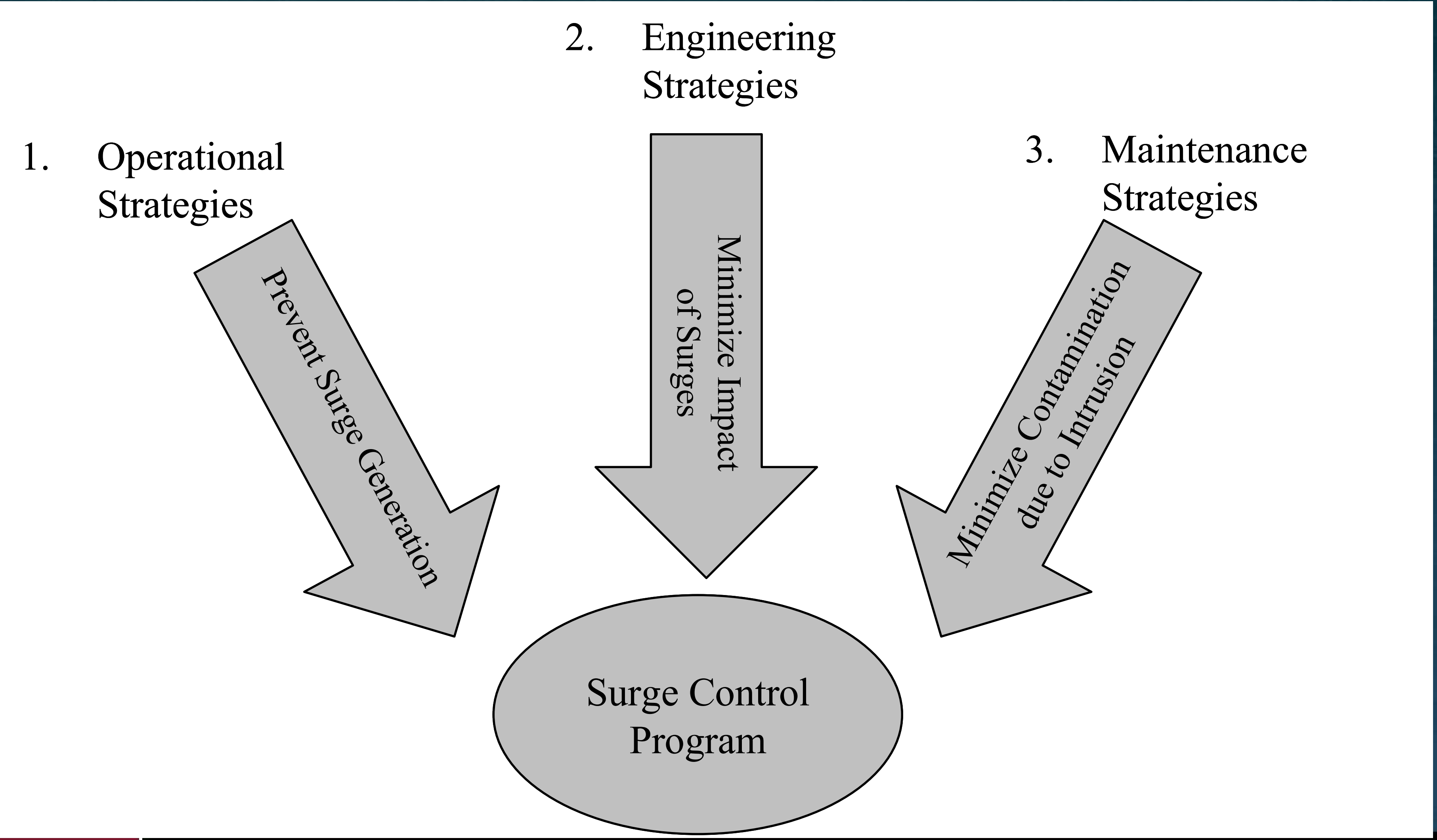
- Pumped (i.e., non-gravity) systems
- Distribution system mains near by and in simple hydraulic connection to pumps
- High elevation areas
- Areas with low static pressures
- Areas far away from overhead storage
- Upstream/downstream of active valves in high-flow areas

Use of Intrusion Data

- Utilities can determine susceptibility to contamination
  - *Conduct sanitary survey in Kirmeyer et al. 2001*
  - *Conduct surge modeling*
  - *Assess annual leakage*
  - *Assess number of transient pressure events, etc.*
- Apply existing BMPs to susceptible areas
  - *Increase monitoring*
  - *Increase disinfectant residual*
  - *Increase cross connection surveys*
  - *Increase leak detection, etc.*
- Develop a systematic intrusion control strategy

Friedman et al. 2004. Verification and Control of Pressure Transients and Intrusion in Distribution Systems

Pressure Transient Control Strategies



Friedman et al. 2004. Verification and Control of Pressure Transients and Intrusion in Distribution Systems

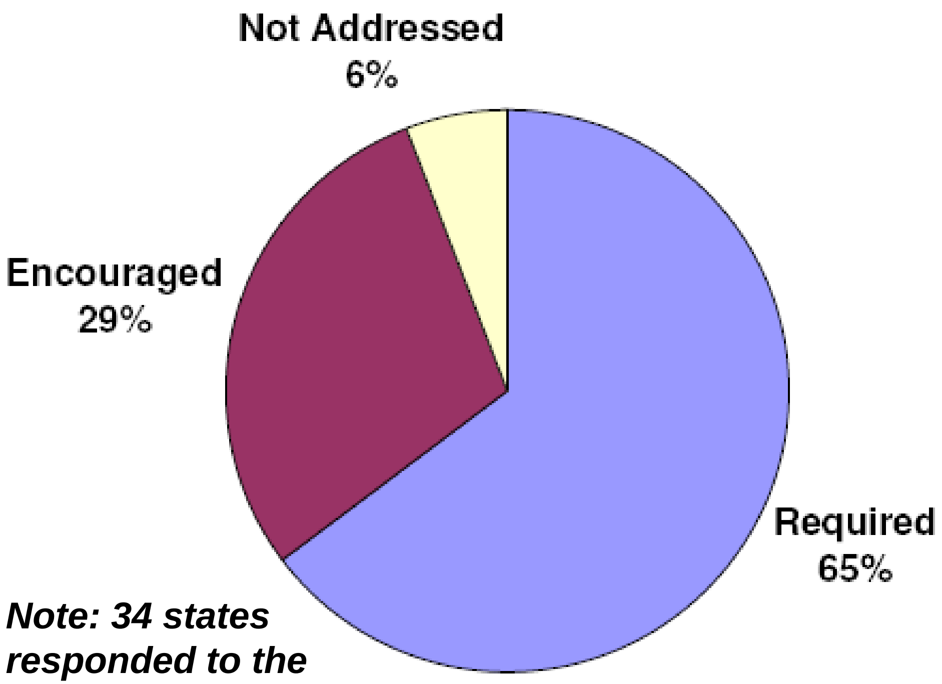
The other side of the story….

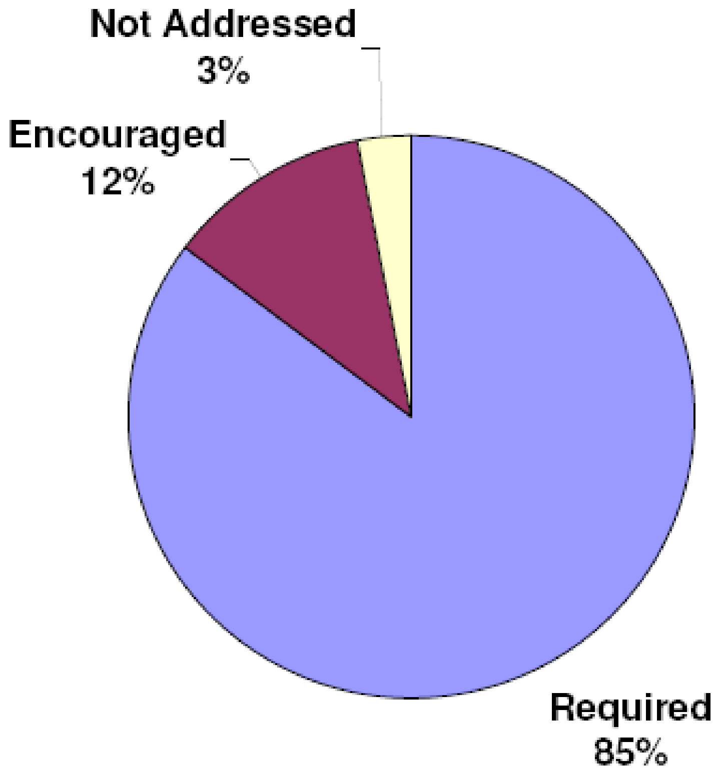
- Transient control strategies can negatively impact water quality
  - *Surge tanks must be periodically mixed and exercised*
  - *Air/vacuum valves can act as contamination pathway*
  - *Increasing static pressures can result in increased leaks and breaks*
  - *Increasing overhead storage can significantly impact water age*

State Requirements Related to Intrusion

Does the state require protection of air-release and air vacuum valves?

Does the state require separation of water mains and sanitary sewers to protect the water main from contamination?

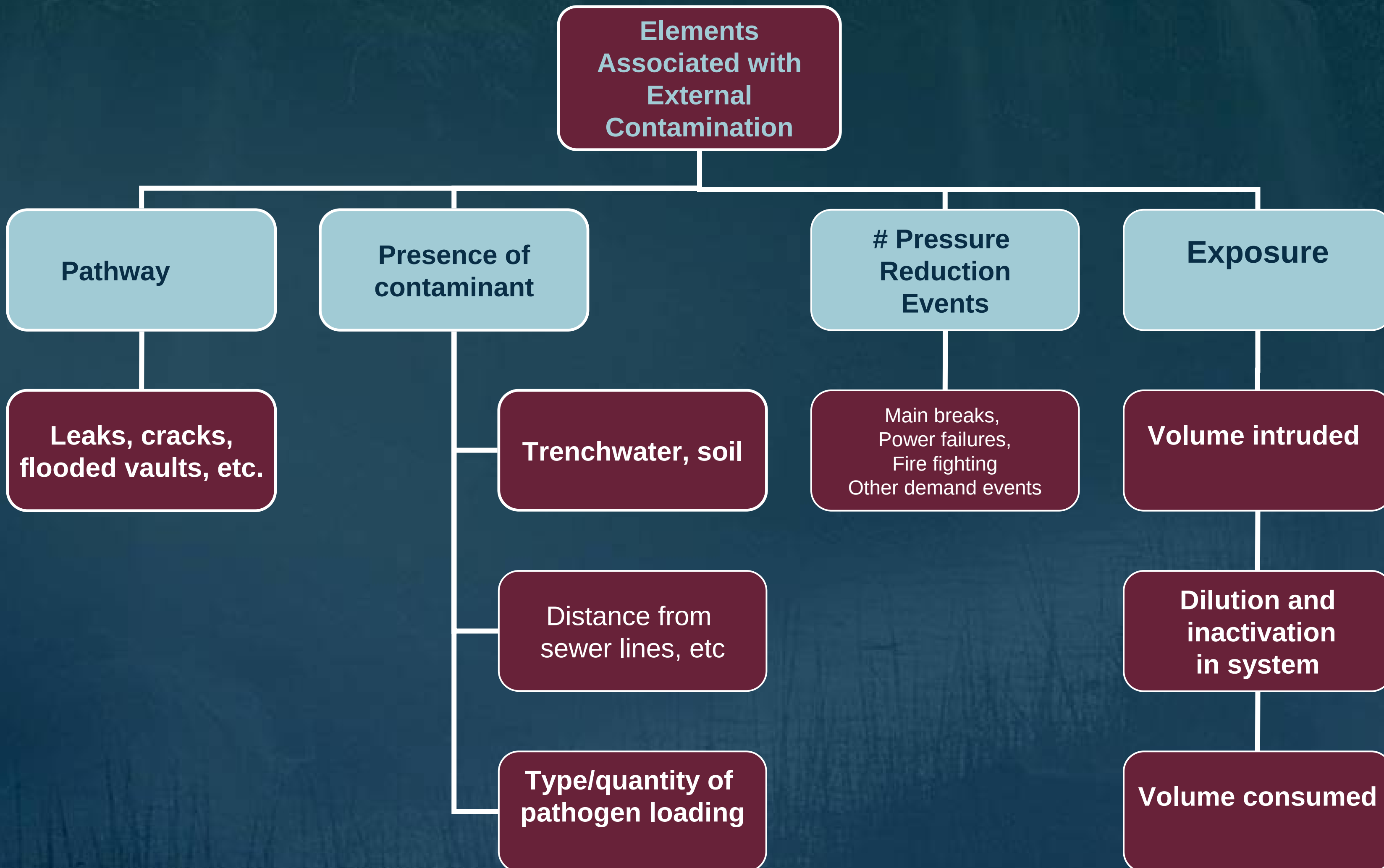




Note: 34 states responded to the survey

ASDWA. Draft Survey 2003.

Summary of Data Sources Needed to Estimate Occurrence of Potential Contamination Due to Intrusion



Physical Integrity Issues

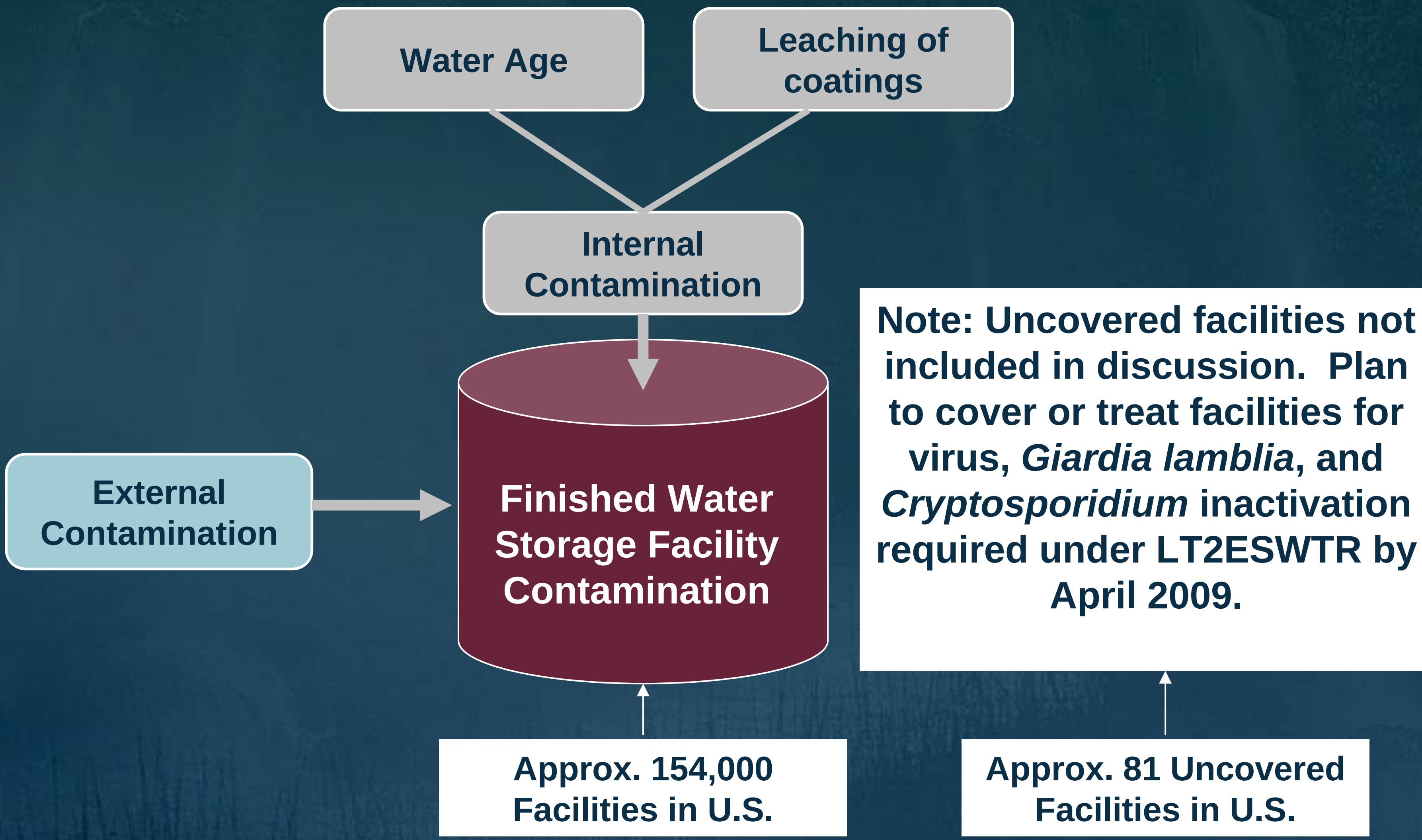
- Intrusion
- Storage
  - Characterize Issue
  - Pathways
  - Contaminants
  - Use of Data
- Main Installation and Repairs

Finished Water Storage Facility Contamination Characterized as a High Priority Issue

- Ranked as a high priority TCR issue based on potential health risks (NRC, 2005)
- Missouri DNR, 1991 – 1994
  - *Largest identifiable cause of boil water orders in water systems having storage tanks*

Missouri DNR. June 2006. Factsheet Microbial Contamination of Water Storage Tanks

Mechanisms of Storage Facility Contamination



Need Pathway and Pathogens for Contamination to Occur

- **Elements Associated with External Contamination**
  - **Pathway**
    - Vents, hatches, screens, overflow piping, etc.
  - **Presence of contaminant/vector**
    - Waterfowl, bats, rodents, other

Information Related to Pathways

Pathway: Number of Facilities Susceptible to Contamination

MO DNR Problematic Inspections:

- *25% to >50% have evidence of contamination*
- *85% have some type of sanitary defect*
- *50% of tanks have a serious sanitary defect*
- *30 – 40% have minor sanitary defects*

Missouri DNR. June 2006. Factsheet Microbial Contamination of Water Storage Tanks.

Maintenance Deficiencies Resulting in Contamination

- Missouri DNR reported that of 51 boil water orders between 1991 to 1993, 18 were caused by birds.

Method of Entry of Birds

Screens/Vents	7
Hole(s)	2
Hatch	4
Unknown	7

REF: Missouri department of Natural Resources. 2006. Fact Sheet: Microbial Contamination of Water Storage Tanks. PUB000172.

Information Related to Presence of Pathogens

Presence of Pathogens

- Waterfowl are Known Carriers of Waterborne Pathogens
  - V. cholerae, *Hepatitis A*, S. Montevideo B, *Norwalk virus*, *Coronavirus*, *Coxsackieviruses*, *Rotavirus*, *Astrovirus*, *Cryptosporidium*, E. coli
  - *Gideon, MO 1993* - Salmonella – 7 *deaths*, *>600 illnesses*

Surface water samples collected on a floating cover had:

- Total coliform counts as high as 33,000 per 100 mL

- Fecal coliform counts as high as 13,000 per 100 mL

Kirmeyer et al. 1999. Maintaining Water Quality in Finished Water Storage Facilities.

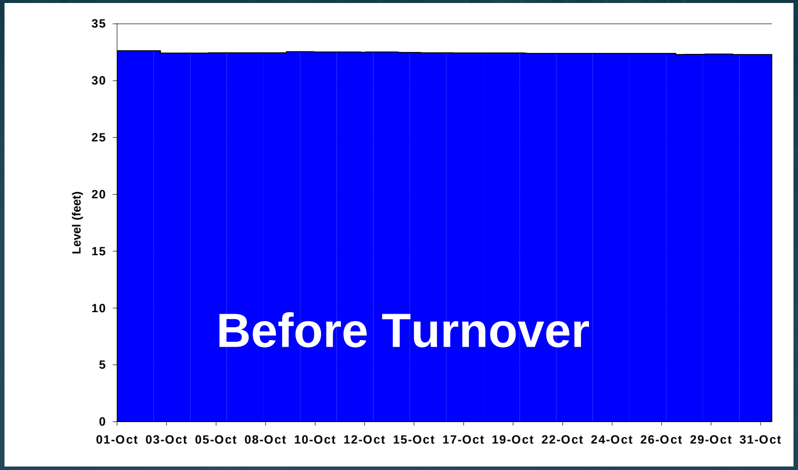
State Use of Facility Contamination Data

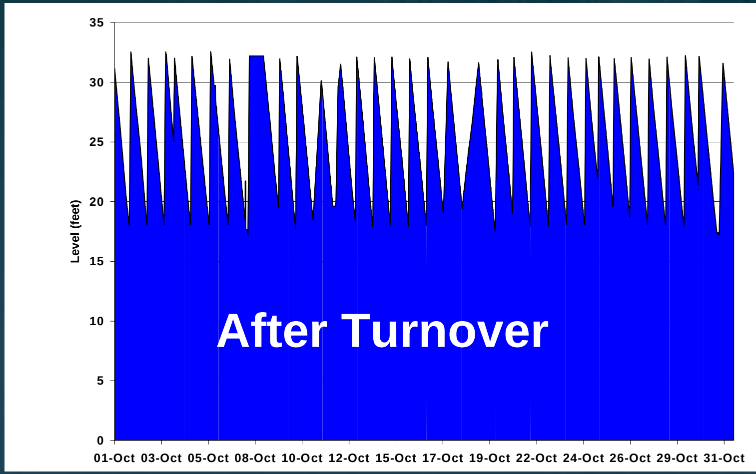
- MO DNR developed education program and recommendations on inspection frequency and monitoring.
- At least 30 State require utilities to follow industry standards regarding vents, hatches, screens, etc.
- At least 15 States require that tanks are designed to ensure adequate turnover
- At least 13 States have requirements for Tank Inspection and Maintenance

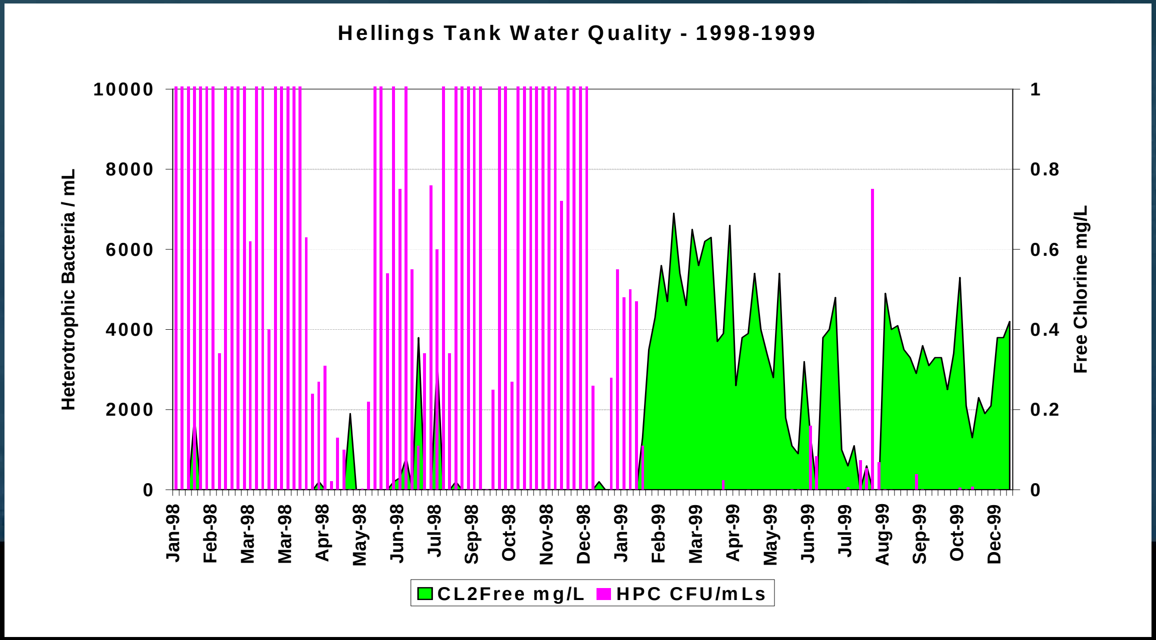
Utility Use of Data to Reduce Risk of Contamination via Storage Facilities

- Increase inspection frequency
- Increase maintenance activities
- Increase monitoring
- Assess turnover/water age
- Increase turnover
- Set disinfectant residual goals
- Remove standing water from floating covers

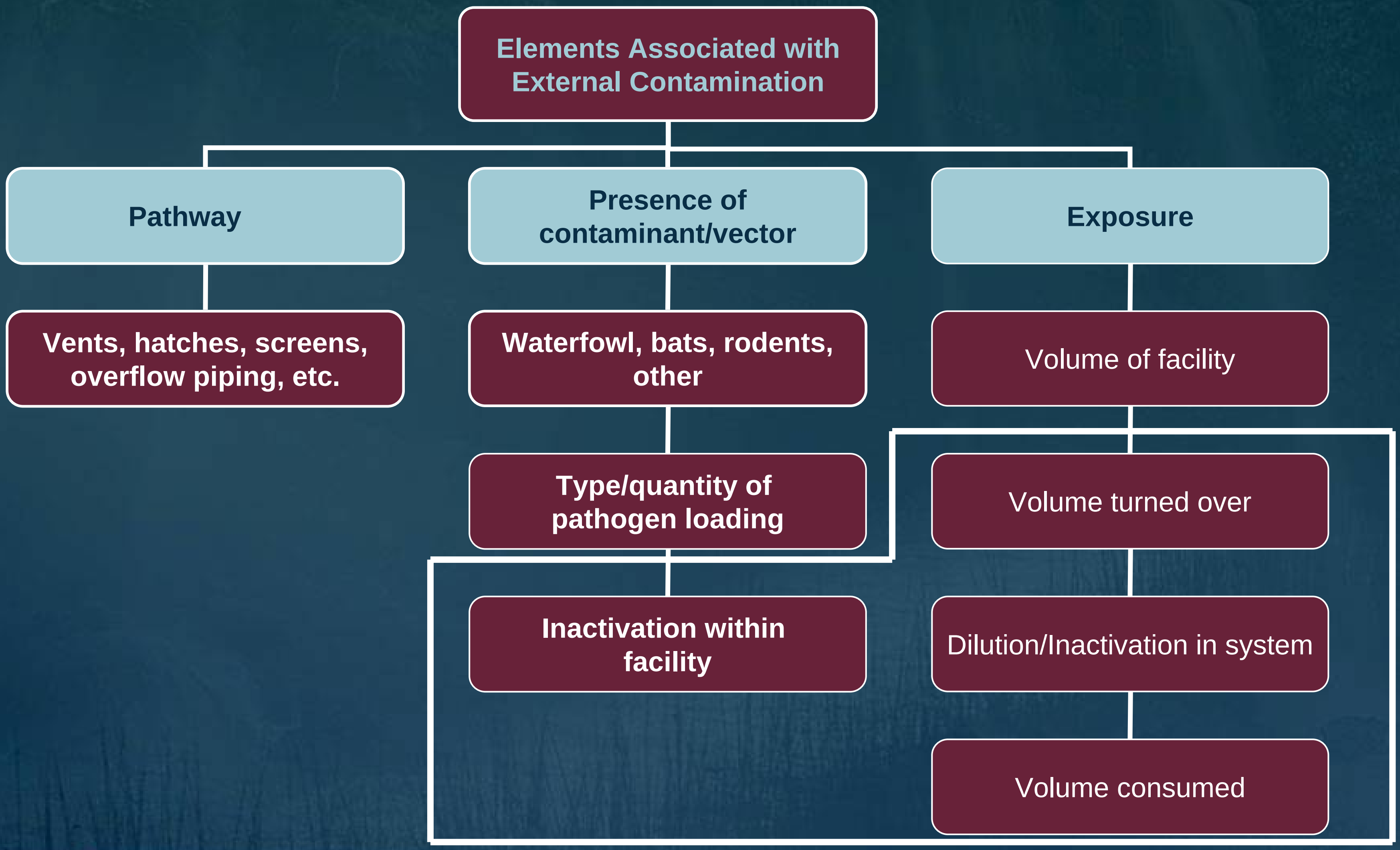
Example of Utility Increasing Turnover to Increase Residual Levels







Summary of Data Sources Needed to Estimate Occurrence of Potential Contamination Due to Storage Facilities



Water Main Installation and Repair

- **Physical Integrity Issues**
  - Intrusion
  - Storage
  - **Main Installation and Repairs**
    - **Pathways**
    - **Presence of Contaminants**
    - **Effectiveness of Control Strategies**
    - **Data Uses**

Contamination During Main Installation and Repair

- Installation, rehabilitation and repair of water mains are common activities in all water systems
- Potential risk of contamination due to frequency and nature of these activities

Contamination During Main Installation and Repair

Key elements required for a Contamination Event to Occur

- **Pathway**
  - **Main Installation and Repair**
    - Data – occurrence of main breaks/ repairs
- **Presence of contaminant**
  - **Pathogens/Vector Present in the Vicinity of Main**
    - Data – type and frequency of contamination
- **Failure of existing control strategy**
  - **Standard Post-Installation or Repair Procedure**
    - Data – effectiveness of existing control strategies

USEPA. EES and AWWA. 2002. New or Repaired Water Mains. Distribution System White Paper. www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_watermains.pdf . Accessed 01/15/2007.

Pathway:
Main Installation and Repair

Background

- Three phases of main installation/repair in which contamination may occur:
  - ***Prior to installation/repair***: *at point of manufacture of replacement pipe or materials; during handling and storage; at the site*
  - ***During installation/repair***: *soil and trenchwater; cross connections; leaching*
  - ***After installation/repair***: *leaking pipe joints; stagnant water in adjacent pipe sections; cross-connections; pressure transients*

USEPA. EES and AWWA. 2002. New or Repaired Water Mains. Distribution System White Paper. www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_watermains.pdf . Accessed 01/15/2007.

New and Replaced Main Data

- 13,200 miles of new pipe are laid each year
  - *Approximately 3.5 million events per year*
- 4,400 miles of pipe replaced* annually
  - *Approximately 1.2 million events per year*
  - *Estimates for replacement rates mean on average a pipe will be replaced less than every 200 years*
  - *Rate of replacement will likely increase for utilities to maintain serviceability*

* Mostly due to leaks or breaks

Kirmeyer, G., W. Richards, and C.D. Smith. 1994. An Assessment of Water Distribution Systems and Associated Research Needs. AWWARF. Denver, CO.

Main Break Data

- Breaks per year per utility by utility size

Utility Size (population served)		<3300	3301-10000	10001-50000	50001-500000	>500,000
Number of CWS		*49069*	*4084*	*2672*	*661*	*50*
Information Source	ABPA	1	13	17	59	188
	Water Stats	10	13	30	228	665
	Kirmeyer *et al*. 1994		5	25	225	730
	Haas 1998	4	13	42	97	488

Notes:
Utility sizes are from EPA data in Haas *et al*. 1998.

Haas, C.N., R.B. Chitluru, M. Gupta, W.O. Pipes, and G.A. Burlingame. 1998. Development of Disinfection Guidelines for the installation and replacement of water mains. Denver, CO. AwwaRF.

Main Break Data

- Breaks per mile by utility size

Utility Size (population served)	<3300	3301-10000	10001-50000	50001-500000	>500,000
Total Number of miles of pipe	*2438*	*6205*	*17434*	*211513*	*1442*
Number of CWS	*49069*	*4084*	*2672*	*661*	*50*
Number of breaks per mile					
ABPA	20.13	8.56	2.61	0.18	6.52
Water Stats	201.27	8.56	4.60	0.71	23.06
Kirmeyer *et al*. 1994		3.29	3.83	0.70	25.32
Haas 1998	80.51	8.56	6.44	0.30	16.93

  – *Compiled from the ABPA, Water Stats, Kirmeyer et al., and Haas estimates of number of breaks per utility, combined with the 2000 EPA Community Water Survey data for total number of miles of pipe for utilities of a given size range*

USEPA. 2000. Community Water Systems Survey. Washington, D.C.

Presence of Contaminant

Potential risk to public health requires presence of a contaminant and depends on:

- Type and quantity of contaminant that enters pipe
- Type and quantity that can continue to enter, if not identified and stopped
- Extent of spread from points of entry
- Effectiveness of disinfection and flushing prior to releasing pipe to service

USEPA. EES and AWWA. 2002. New or Repaired Water Mains. Distribution System White Paper. www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_watermains.pdf . Accessed 01/15/2007.

Examples of Contamination Sources

- Occurrence of organisms in the environment of the distribution system or areas of main repair
  - *External soil or water*
  - *Runoff*
  - *Animals*
  - *Unsanitary handling of pipe or components*

Kirmeyer, G., M. Friedman, K. Martel, D. Howie, M. Lechevallier, M. Abbaszadegan, M. Karim, and J. Funk. 2001. Pathogen Intrusion Into the Distribution System. AwwaRF. Denver, CO.

Case Study: Potential for contamination during main installation and repair

- Survey of 46 Philadelphia, PA construction inspectors found sanitary problems were common during main installation and repair
  - *Environmental dirt gains entry to pipe*
  - *Runoff enters trench*
  - *Positive pressure lost before site secured*
  - *Replacement parts dirty*
  - *Could not inspect in-place pipe before repair was made*

How Has Data Been Used?

- The data was used for a decision-making process to:
  - *Document range and occurrence of potential sources of contamination during pipe installation and repair*
  - *Remove sources or create barriers to sources of contamination*
  - *Develop more effective control strategies e.g. improved procedures and protocols for pipe installation and repair (discussed in next section on Control Strategies)*
- The decisions made based on the data impacted the three elements: Pathway, Contaminant Presence and Control Strategies

Pierson, G., K. Martel, A. Hill, G. Burlingame, A. Godfree. Practices to Prevent Microbiological Contamination of Water Mains. AwwaRF. Denver, CO.

Failure of Existing Control Strategies

Background

- New main installation typical control strategies include:
  - *release to service protocols*
  - *flushing*
  - *disinfection*

- For main breaks, additional strategies include:
  - *rapid detection*
  - *physical isolation*
  - *removal or inactivation of contaminant source*
  - *repair under pressure*

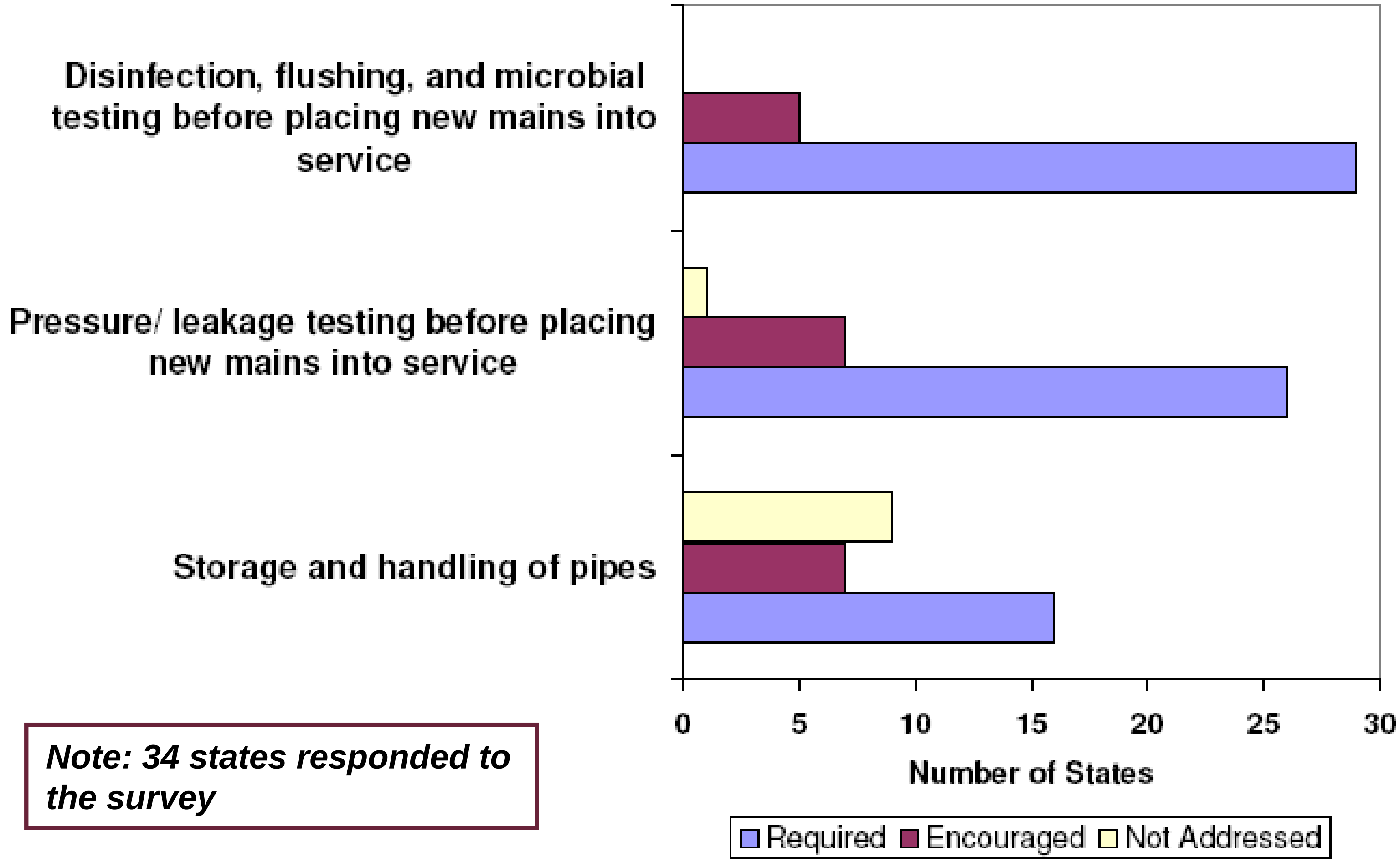
USEPA. EES and AWWA. 2002. New or Repaired Water Mains. Distribution System White Paper. www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_watermains.pdf . Accessed 01/15/2007.

Best Management Practices

- AWWA standards
  - *C600 – Pipe storage and handling during construction*
  - *C651 – Construction & Disinfection Practices*
- 10-State-Standards- incorporates AWWA standards by reference (e.g. installation, post-installation disinfection, pressure and leak testing)
- AwwaRF 90869A (Pierson *et al.*,2001) BMPs including
  - *Pipe caps or covers until pipes are joined*
  - *Disinfection of fittings, joints, valves etc.*
  - *Positive flow shutoff*
  - *Adequate field operations and inspector training*
  - *Utility documented release to service criteria*
- Distribution System White Paper*

Pierson, G., K. Martel, A. Hill, G. Burlingame, A. Godfree. 2001. Practices to Prevent Microbiological Contamination of Water Mains. AwwaRF. Denver, CO.
* USEPA. EES and AWWA. 2002. New or Repaired Water Mains. Distribution System White Paper. www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_watermains.pdf . Accessed 01/15/2007.

State Requirements Related to Main Installation and Repair



Note: 34 states responded to the survey

ASDWA. Draft Survey 2003.

Two Types of Data for Evaluating Control Strategies

1. Are control strategies documented and used by utilities and contractors?

2. How effective are these strategies in reducing potential contamination?

Data: Utility Surveys

- Whether control strategies are used

Control Strategy	How often Used	Source
Disinfection of trench areas	24% apply hypochlorite	Haas et al 1998
Specify AWWA Standard C651 for disinfecting water mains in construction documents	75%	Haas, 1998
Check minimum disinfectant levels in field	76%	Haas, 1998
Disinfect connection materials prior to connection of a main into the system	71%	Haas, 1998
Maintain water quality database for main breaks and new main construction	20%	Haas, 1998
Inspectors trained on AWWA standard	35%	Haas, 1998
Inspectors trained on utility specifications	30%	Haas, 1998
Mains repaired under pressure	15% utilities- mostly 26% utilities - none	Kirmeyer *et al.* 2001

Haas, 1998 = 250 responses

Haas, C.N., R.B. Chitluru, M. Gupta, W.O. Pipes, and G.A. Burlingame. 1998. Development of Disinfection Guidelines for the installation and replacement of water mains. Denver, CO. AwwaRF.
Kirmeyer, G., M. Friedman, K. Martel, D. Howie, M. Lechevallier, M. Abbaszadegan, M. Karim, and J. Funk. 2001. Pathogen Intrusion Into the Distribution System. AwwaRF. Denver, CO.

Data: Case Studies

- **How effective are control strategies?**
  - ***Northwest Water, UK testing protocols after flushing and disinfecting main***
    - **Require microbiological testing and documentation of sample results on a standard form**
    - **Require completed form and satisfactory results before main can be released to service**
  - ***Philadelphia PA***
    - **Requires detailed disinfection, flushing protocol followed by chemical and microbiological testing – at least one sample every 500 meters**
    - **If one sample fails the entire job is rejected**

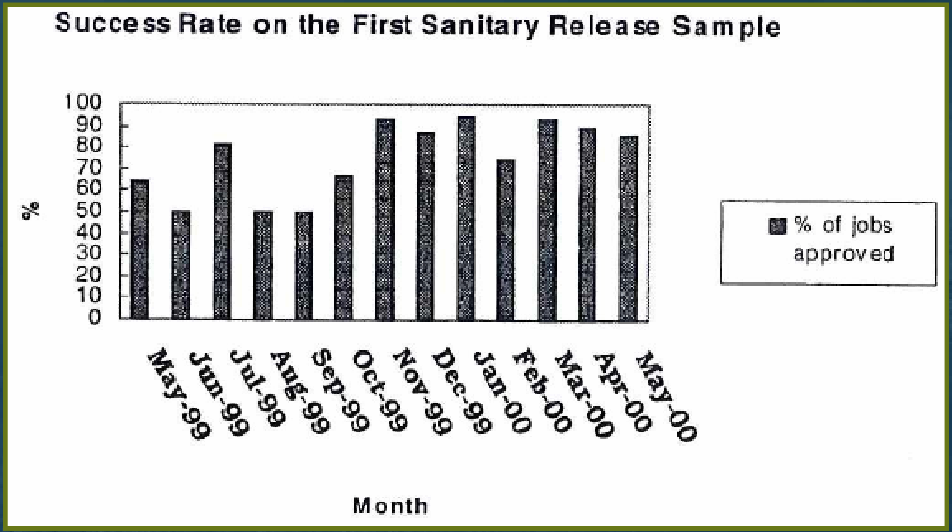
Not all utilities wait for results before releasing repaired mains into service.

Anecdotal information: utilities estimate that results come back satisfactorily 98-99% of the time.

Pierson, G., K. Martel, A. Hill, G. Burlingame, A. Godfree. 2001. Practices to Prevent Microbiological Contamination of Water Mains. AwwaRF. Denver, CO.

How Has Data Been Used?

- **Philadelphia field survey data (contamination sources etc.)**
  - ***improved procedures and protocols for pipe installation and repair***
- **Philadelphia main release data (microbiological testing)**
  - ***determined effectiveness of control strategies and need for additional testing and control steps***
- **Since those improvements, more mains pass release inspection first time**
  - ***evidence that the control strategies are effective***



Pierson, G., K. Martel, A. Hill, G. Burlingame, A. Godfree. Practices to Prevent Microbiological Contamination of Water Mains. AwwaRF. Denver, CO.

Summary of Data Sources Needed to Estimate Occurrence of Potential Contamination Due to Main Installation/Repair

Key elements required for a Contamination Event to Occur

- **Pathway Data – occurrence of main breaks/ repairs**
  - Estimates from national and other databases of frequency of occurrence of main breaks/repairs
  - Data on infrastructure age and statistics for predicting future failure and replacement rates
- **Contaminant Data – type and frequency of contamination**
  - Field Samples - Soil and Water Data
  - Utility surveys for presence of contaminants or disease vectors before and during repairs
- **Failure of Existing Control Strategies**
  - Survey data on utilities using preventive strategies
  - Post-repair test results that document strategy effectiveness
  - Case studies of failed strategies, utility records of release to service criteria
- Volume Consumed

In Summary

- The number of potential contamination "events" can be estimated
- Extent of contamination of drinking water through these three pathways has not yet been quantified
  - *Intrusion, storage facilities, main installation/repair*
  - *There is little information regarding the type and extent of contamination present in water main trenches, etc…*
  - *Only a few documented incidents of storage facility contamination*
- Industry BMPs and State requirements exist to minimize the breaches (i.e. pathways) as well as to reduce transient pressure conditions (i.e. the driving force), and to inactivate/remove contamination after main installation and repair
  - *The extent of implementation and documentation has not been quantified*